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Assessment of Off-shore Wind Energy Resource in China using QuikSCAT Satellite data and SAR Satellite Images

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Abstract - From August 2008 to August 2009, the project 'Off-Shore Wind Energy Resource Assessment and Feasibility Study of Off-Shore Wind Farm Development in China' was carried out by China Meteorological Administration (CMA), which was funded by the EU-China Energy and Environment Programme (EEP). As one part of the project, off-shore wind energy resource in China was assessed with QuikSCAT Satellite data and SAR Satellite Images. In this paper, the results from these two ways were introduced.

I. Analysis of wind resource using QuikSCAT Satellite data

NASA Polar Orbiting Satellite QuikSCAT uses backscattering echoes to detect sea surface height. By interpretation of the QuikSCAT images, the wind distribution over the sea can be obtained. Comparison between QuikSCAT data and measured data from the offshore wind farm Horns Rev in Europe shows that correlation between these two datasets is high, up to 0.91 (Hasager, et al., 2006).

QuikSCAT scans twice per day to provide global data with horizontal resolution of 12.5km by 12.5km since July 1999. In this study, full years from 2000 to 2007 were selected from all data available since July 1999.

QuikSCAT data has been processed by NASA and divided into two groups; A.R. and DIRTH (two models using satellite data to interpret the offshore wind speed). Data used in this study are those labeled "the best data", i.e. wind speed between 3m/s and 20m/s, which is equivalent to an effective wind speed. The research sea area is defined between 15N-45N and 105E-135E along the Chinese coastline. Due to the drift of the satellite orbit, the location of observation points is not fixed every day. Therefore, a 0.1° grid is applied in the research area by inserting all data into the grid nodes and daily averages are calculated. Then annual average effective wind speed and average effective wind power density can be derived at each grid node.

A. Comparing QuikSCAT data and offshore measured data

The study area of this project covers the East China Sea. Meteorological measured data from Shanghai offshore masts are used to compare the QuikSCAT data.

Shanghai offshore masts located outside 7 ~ 8km away of Fengxian District, Shanghai. The coastal area is flat. The altitude is below 50m around nearby at the area within a radius of 100 kilometers. Zhejiang hilly area located southwestern 200 kilometers away. A peak above 600 meters altitude located there. The accuracy of QuikSCAT data in this area could be obtained through analyzing the relationship between the mast and the QuikSCAT data.

Height of offshore mast is 70m. NOMAD wind measure equipments from Second Wind Ltd are assembled. Anemometers were installed at 70m, 60m, 50m, 40m, 25m, and 10m. Time period is 2007. Hourly averaged wind speed range is between 0 to 40 m/s, while hourly averaged wind direction is between 0 to 360. The correlation coefficient between Mast data and the satellite synchronized observation data at height of 70m, 60m and 50m are above 0.99, while 0.87 in 10m. High correlation coefficient area is located the Yangtze River estuary Regional at northeast of mast and the Hangzhou Bay area at the south of mast (see Figure 1). The depth of Waters in the south of mast is between 7.2~8.1m. The northeast of the mast is the Yangtze River alluvial flat, with a water depth of 0.8 ~ 5.6m.

Satellite observed twice a day. The records in the corresponding time in the mast measured data were picked up as the comparative data, 349 pairs in northeast area, and 106 pairs of southern waters. The averaged wind speed in the two above area and the mast were calculated. The Weibull shape parameter K and scale parameter C were calculated too. All the results are listed in table 1 table 2. Obviously, the averaged wind speed in southern deep water area more close to the mast measured data at the height of 70m, but slightly higher. So satellite remote sensed wind speed is equivalent of the wind speed in the top of 70m mast. The differences of Weibull parameter K is less between northeastern waters data and mast data, while the scale parameter C from southern satellite remote sensing is more close to the mast data.

B. The distribution of China's offshore wind energy resources by analyze QuikSCAT satellite data

The average annual wind speeds were calculated with the high credibility QuikSCAT data which were marked without the influence of precipitation from 2000 to 2007 (Figure 2). From eastern Guangdong to the middle of Zhejiang offshore the average annual wind speed is up to 8

m/s. The biggest annual wind speed is in Taiwan Strait, 8 to 9 m/s. From north Zhejiang to the Yangtze River Estuary, the annual averaged wind speed is 7 to 8 m/s. From the middle Guangdong offshore to western Guangdong offshore, the annual averaged wind speed is between 6.4 and 8 m/s. The annual averaged wind speed is from 5.8 to 7 m/s at North Bay. There is a distribution that wind speed in the middle area larger than the both sides in the Yellow Sea waters, among where the annual averaged wind speed in south Jiangsu offshore area is from 6.4 to 7 m/s. The range of the annual averaged wind speed in Bohai Sea and north of the Yellow Sea is from 5.8 to 6.4 m/s.

C. The average annual effective wind power density

The range of annual effective wind power density of Bohai Sea and Yellow Sea is 300 to 400 W/m^2 (Figure 2), while 400 to 600 W/m^2 for south of the Yangtze River estuary to the middle of Zhejiang offshore, 600 W/m^2 for middle of Zhejiang offshore to eastern Guangdong offshore, 800 to 1200 W/m^2 for the Taiwan Strait where is the maximum part, 400 to 600 W/m^2 for middle of Guangdong offshore to the North Bay, 300 to 400 W/m^2 for the vicinity of Hainan Island.

II. The application of aperture radar (SAR) in the offshore wind resource assessment

A. Measurement wind at sea surface using SAR

Synthetic Aperture Radar (SAR) is a high-resolution imaging sensor, with a full-time and all-weather observation capability. The use of SAR remote sensing instruments can be multi-band, multi-polarization, multi-angle observations on remote-sensing targets. In the marine applications, the observations of using SAR can be macroscopic, long-term, continuous, dynamic, real-time ocean. In addition, SAR imaging mechanism enables it to observe the waves, internal waves, seabed topography, shallow water depth, the boundary flow and the peak surface and so on. Their images can also be applied to the sea wind, ships objectives, detection of oil-slick pollution, and shoreline changes, etc. Therefore, SAR images have a unique value in the marine rights and interests, resource surveys, environmental protection, disaster prevention and mitigation and marine scientific research.

Since the 90s of 20 century, Europe and the United States launched a number of satellites of carrying the satellite SAR sensors for the monitoring and research of atmospheric, ocean and land, including the offshore wind resource testing and evaluation. The main advantage of use of SAR images in offshore wind resource assessment is of its high resolution and coverage of coastal area. The horizontal resolution of wind field using inversion of SAR image data can be around over 1km (maximum up to tens of meters or even 1 m), while resolution of the other satellite remote sensing (such as scatterometer and passive microwave remote sensing instrument) tends to be more rough and the data is not available within the coast to offshore approximately 25km. Thus, SAR images are paid more and more attention in the European wind power sector in recent years.

ESA (European Space Agency, ESA) launched the ENVISAT polar-orbiting satellites on March 1, 2002 monitored. Its images ASAR (Advanced SAR) have a lot application in the assessment of offshore wind in European in recent years. This section focuses on the fundamentals

of use of ASAR image inversion on sea surface wind, the image selection method and its application in China's offshore wind resource assessment applications.

B. Assessment from Jiangsu Province to Hangzhou Bay using ASAR image

There is a long coastline in the east of China with rich offshore wind resource, which could be developed for wind power on a large scale. The following example is the analysis of ASAR image for wind resource characteristics from the coastal areas of Jiangsu Province to Hangzhou Bay. Figure 3 shows a major area of concern with a horizontal distance 600km.

After inspection, there are more than 300 copies of ASAR images under the above selection criteria since March 2002, excluding the images which only covers the edge of the region, or mainly covers the land or significantly affected by atmospheric and ocean. After this selection, there are 147 images left.

The single SAR image were processed into distribution of wind speeds by using SAR/wind inversion software (APL / NOAA SAR Wind Retrieval Software, ANSWRS) developed by Johns - Hopkins University Applied Physics Laboratory (JHU/APL). A joint statistical analysis was carried out on 147 images to obtain a comprehensive wind resource maps by using S-WAsP (Satellite Wind Atlas Analysis and Application Program) software developed by Risø DTU.

A certain number of wind observations data were fitted as Weibull function in the designated areas using S-WAsP. The statistical results were reasonable only by a superposition of about 100 Satellite images at each grid point (Barthelmie & Pryor, 2003; Pryor et al., 2003). This process is called "regional statistics."

Figure 4 shows the overlapping ASAR image from Jiangsu to Hangzhou bay. It can be seen that the maximum number of overlapping images are 101 copies, while the number of overlapping ASAR images from Shanghai to south of Jiangsu is over 70 copies (white box). The statistical results of wind resource based on the analysis are credible. The overlapping ASAR image is less than 50 copies in the northern part of Jiangsu Province, therefore there exists a large randomness for the statistical results of wind resource.

Figure 5 shows the distributions of wind speed and wind power density from Jiangsu offshore to the Hangzhou Bay area at 10m height, of which the horizontal resolution is $1\text{km} \times 1\text{km}$. It can be seen in the figure that the wind speed basically is 7m/s at the offshore area, while the wind speed reaches 9.5m/s at the distance 100km from the coast.

Wind power density is 300W/m² at the offshore area, while the wind power density reaches 9.5m/s at the distance 100km from the coast. Both the wind and wind power density reduces radically in the region at the southeast of Hangzhou Bay. In addition, two bright red areas in the map don't stand for high wind speed or wind power density because the brightness were changed at sea beach or mudflat.

In addition to performing the "regional statistics," "single-point statistics" can also be carried out. Based on above inversion of data, the corresponding average wind speed, wind power density, Weibull parameters and the uncertainty of each value and wind rose could be obtained by put the concerned latitude and longitude of a point in the region in S-WAsP software.

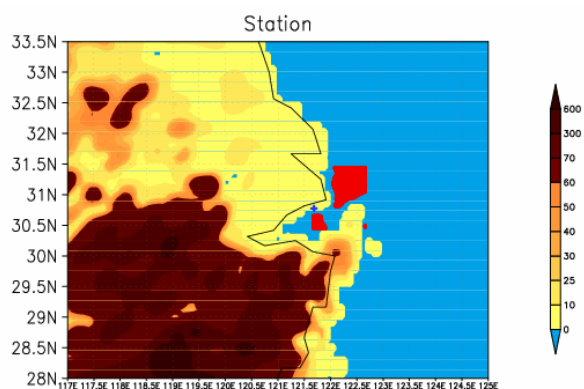


Fig. 1. Correlation map of Shanghai offshore wind towers and satellite remote-sensing data

Table 1. The results of mast data comparing satellite data in the southern waters (106 samples)

	10	25	40	50	60	70	Q
M_u	5.87	6.35	6.62	6.83	6.93	7.07	7.17
W_k	2.66	2.78	2.77	2.83	2.77	2.77	2.59
W_c	6.61	7.14	7.44	7.67	7.79	7.95	8.07

Table 2. The results of mast data comparing satellite data in the southern waters (349 samples)

	10	25	40	50	60	70	Q
M_u	5.86	6.30	6.57	6.76	6.85	6.97	8.67
W_k	2.62	2.70	2.67	2.73	2.67	2.65	2.62
W_c	6.59	7.08	7.39	7.60	7.71	7.85	9.75

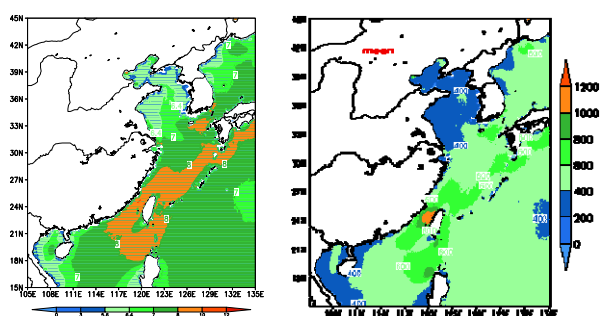


Fig. 2. The average annual wind speed (left) and effective wind power density (right) distribution from QuikSCAT from 2000 to 2007

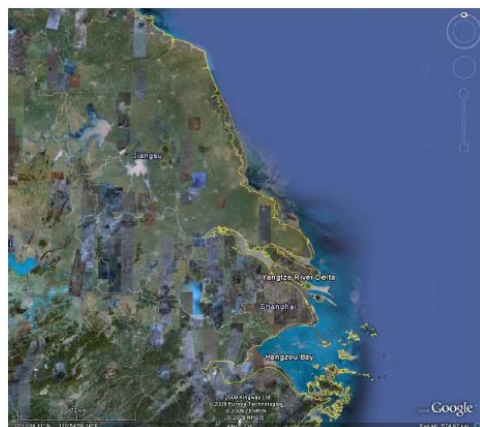


Fig. 3. Coastal area from Jiangsu Province to Hangzhou Bay (Data source: Google Earth)

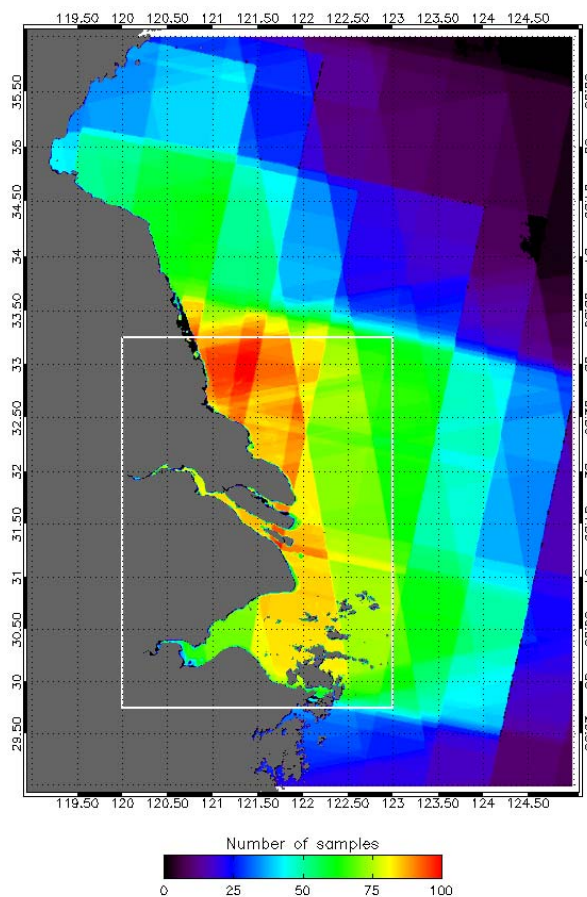


Fig. 4. The distribution of overlapping ASAR images (The number within the white box are above 70 copies)

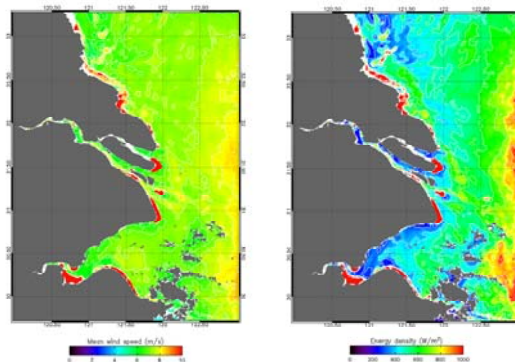


Fig. 5. Offshore wind speed (left) and wind power density (right) at 10m height

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